

A 6.5 WATT AUTO RADIO AMPLIFIER WITH DIRECT COUPLING

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I. INTRODUCTION

An improvement in the performance of automobile radio audio amplifiers can be realized at no extra cost by using this design which features two NPN silicon planar transistors in conjunction with a PNP germanium power output transistor.

The present availability of silicon transistors for consumer entertainment equipment, the reduced number of costly parts, the uniform transfer characteristics of the silicon transistors giving stable d-c biasing feedback, and the inherent thermal stability of the circuit, are combined to make this design desirable. As a power output level in excess of normal requirements was easy to achieve, the design objective was to maximize power gain along with good thermal and d-c stability, and at the same time keep total component cost to a minimum.

Figure 1 shows the circuit which was built as a result of the design. Operation of the circuit showed that the stabilization feedback loop reduced the maximum power gain by less than 3 db and the maximum power output was 6.5 watts.

Operating temperature range of this circuit is from -55°C to $+75^{\circ}\text{C}$ without special compensating devices.

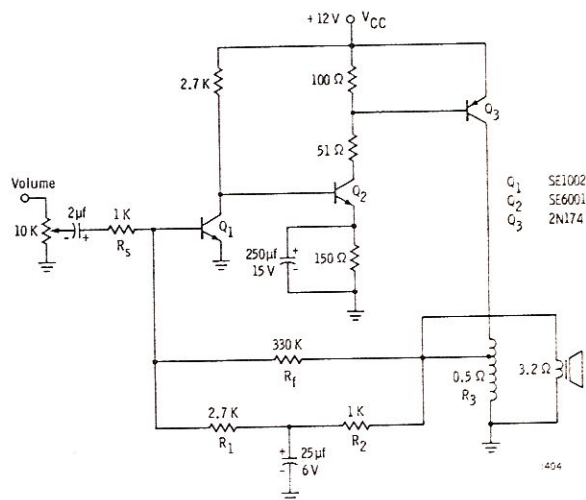


FIG. 1. 6.5 watt auto radio amplifier.

II. CIRCUIT DESCRIPTION

The first transistor, Q_1 , is a high-gain low-level stage with the collector of Q_1 connected directly to the base of the driver transistor, Q_2 , replacing the usual driver transformer. Both of these transistors are Fairchild silicon planar types SE1002 and SE6001 which are packaged in solid epoxy for mechanical strength and protection.

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April, 1963

The collector of Q_2 connects directly to the base of the PNP output transistor type 2N174 so that it is part of Q_3 's bias network. The output circuit with collector choke coupling to the loud-speaker is conventional except for the 0.5-ohm stabilizing resistance which is necessary for d-c feedback.

Class A operating current for the 2N174 transistor to produce 6.5 watts audio output and with less than one ohm resistance loss was determined to be 1.5 amperes. The 2N174 has a power dissipation rating of 50 watts with a $0.67 \text{ W}/^\circ\text{C}$ derating factor, hence, 75°C was selected as a maximum safe operating temperature.

Thermal Stability

Temperature stability of most power amplifiers is achieved through brute force methods or more refined methods such as compensating diodes or thermistors. In this circuit, however, a negative temperature coefficient is built into the biasing scheme.

The base-emitter voltage (V_{EB}) of the SE1002 transistor operating at 3 mA, the selected Class A current, has a temperature coefficient of $-2 \text{ mV}/^\circ\text{C}$. Therefore, the nominal 680 mV base-emitter voltage of this transistor at 25°C can be expected to drop to 580 mV at a temperature of 75°C and to rise to 840 mV at -55°C . This characteristic is shown in Fig. 2. As the voltage drop across the base drive biasing network is h_{FE} dependent, the base drive current of Q_1 increases with increasing temperature. The increase appears phase reversed as decreasing bias current to Q_2 which tends to decrease the base current of Q_3 . This helps counteract the large increase in h_{FE} of Q_3 with increasing temperature. The overall effect is a moderate over-compensation of the base-emitter voltage effects as shown in Fig. 3. The

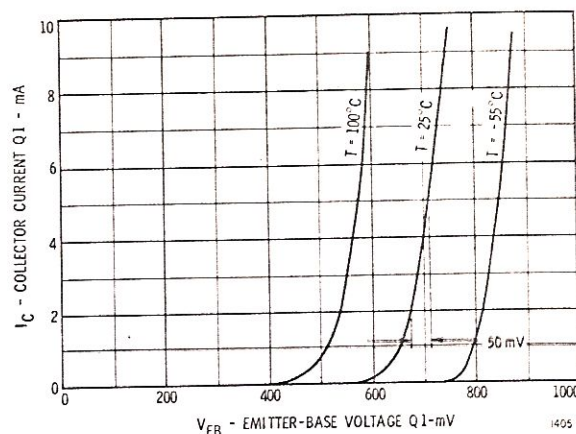


FIG. 2. Emitter-base voltage characteristic of Q_1 .

positive temperature coefficient of the 0.5-ohm choke winding resistance in the Q_3 collector circuit slightly increases this over-compensation. These offer the additional safety factor that the dissipation of Q_3 decreases with increasing temperature.

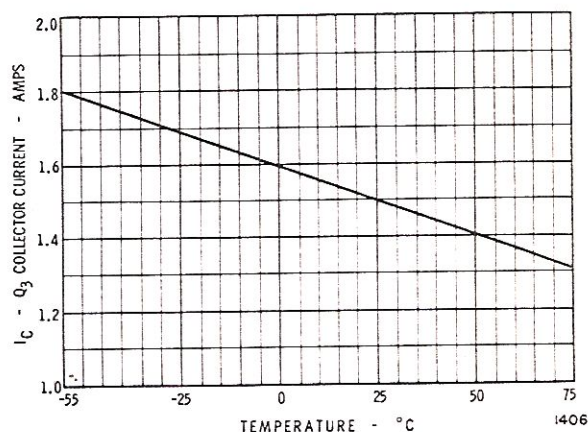


FIG. 3. Temperature compensation of $I_C (Q_1)$.

D-C Stability

The focus point for d-c stability calculations is the base of Q_1 . Q_1 has a base-emitter voltage (V_{EB}) of 680 mV and at 3 mA collector current its h_{FE} is typically 110. The collector current of Q_3 is out-of-phase with the current into the

base of Q_1 as the circuit contains three phase reversals. Thus the voltage across R_3 is out-of-phase with the voltage of Q_1 . The d-c loop is closed with R_1 and R_2 which biases the base of Q_1 . Audio filtering is provided by the 25 μ f capacitor between the two resistors and ground. The resistance of this bias path is made as low as possible in order to minimize the voltage change across the resistors due to the variation in h_{FE} of Q_1 . A total of 3.7 kilohms was chosen to allow for a suitable input resistance for Q_1 and for sufficient audio filtering across R_2 .

Derivation of the range of bias currents is as follows:

The voltage across the bias path is

$$V_B = R \cdot I_C(Q_1) / h_{FE}(Q_1)$$

where

R = Total resistance of path

$I_C(Q_1)$ = Collector current of transistor Q_1

$h_{FE}(Q_1)$ = D-C forward current transfer ratio of Q_1

For a typical h_{FE} of 110, then, V_B is 100 mV and the drop across R_3 becomes 780 mV. If the expected spread of h_{FE} between transistors is 50 to 400 with I_C equal to 3 mA, the V_B will range from 220 mV to 28 mV, an 8:1 variation. An additional variation in voltage drop across R_1 plus R_2 can be expected due to distribution of V_{BE} among transistors which could be equal to ± 50 mV.

Summarizing these possible variations, the voltage drops across R_1 and R_2 from the mean value of 100 mV is +170 mV and -122 mV. This results in a collector current range of Q_3 from 1.32 to 1.90 amperes.

If the spread of h_{FE} is reduced to 100 to 400, the collector current range of Q_3 will be held between 1.32 and 1.68 amperes which is less than a 20% change. Transistors with betas of 50 to 1000 have been tried in this circuit with the results as shown in Table I.

TABLE I

No. Q_1	h_{FE}	V_{EB}	$I_C(Q_3)$
1	50	0.71 V	1.75 A
2	100	0.69 V	1.55 A
3	200	0.66 V	1.42 A
4	1000	0.69 V	1.32 A

Supply Voltage Variations

Supply voltage variations have relatively small effect on the current through Q_3 because I_C is mainly dependent upon the V_{EB} of Q_1 in the feedback loop. The value of V_{EB} changes very little with change in I_C of Q_1 . For example, the V_{EB} change in Q_1 for an I_C range of 2 to 5 mA will be less than 50 mV as shown in Fig. 3. The Q_3 current varied between 1.4 to 1.7 amperes over a 9 to 18 volt range, or about 20% for a 2 to 1 voltage change.

III. AMPLIFIER PERFORMANCE

A tone control can easily be included as part of the audio feedback circuit. In the experimental circuit the 1 K series input resistor, R_s , and the 330 K feedback resistor, R_f , are arranged to provide feedback distortion improvement and some overall gain control. These can be incorporated into the tone and compensation circuits where desired. Specifications and distortion are given in Tables II and III respectively, and frequency response is shown in Fig. 4.

TABLE II

AUDIO AMPLIFIER SPECIFICATIONS

Typical Power Gain	74 db (for 4 watts output)
Typical Power Gain (Open Loop)	84 db
Stabilization Loop Voltage Gain (D-C)	17.3 times
Z_i - Input Impedance	2.3 K Ω

TABLE III

TOTAL HARMONIC DISTORTION AT VARIOUS POWER LEVELS

Power Out	100 cps	400 cps	1 kc	10 kc
1 W	1%	1.4%	1.4%	4.3%
2 W	1.5%	2%	2%	>10%
4 W	2.8%	3.2%	3.2%	—
6.5 W	9.2%	9.8%	10%	—

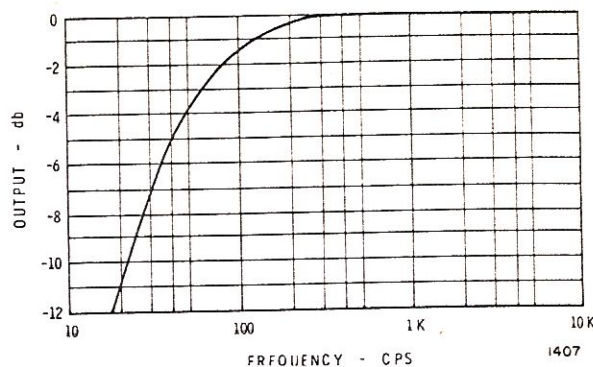


FIG. 4. Frequency response of amplifier.

IV. CONCLUSION

The two silicon transistors used are a high-gain audio amplifier and an audio driver specifically for entertainment equipment.* These transistors are basically similar to metal-can types (TO-5, TO-18 etc.) which are known for high reliability and high performance in non-consumer applications. The uniform transfer characteristics of these transistors is taken advantage of in this amplifier design resulting in very stable and dependable performance. The use of such amplifiers in future automobile radio designs will add to the growing trend to use silicon devices in consumer products.

*Silicon Audio Transistors for use in Consumer Equipment

TYPE	DESCRIPTION	CHARACTERISTIC
SE1002	High-Gain, Low-Level Amplifier	$h_{FE} = 100 - 300$ at $I_C = 3 \text{ mA}$
SE6001	Audio Driver	$h_{FE} = 40$ min at $I_C = 30 \text{ mA}$

Acknowledgment: This article appeared in Electronic Design, published by Hayden Publishing Co., July 5, 1963.